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Repellent toxicity of mint essential oils against rice weevil, *Sitophilus oryzae* L.

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Abstract
Four species of mint essential oils were tested in the laboratory for their repellent toxicity against rice weevil *Sitophilus oryzae* L. at different concentrations in the Insectary, Department of Agricultural Entomology, Agricultural College and Research Institute, Madurai, Tamil Nadu during 2021-22. In comparison with other mint oils, the spearmint essential oil (*Mentha spicata*) possessed the highest repellency effect against *S. oryzae* at 12 nL/cm^2 (66.66%) after 24 hours of exposure, which comes under class IV repellency. Next in order of repellency was *M. piperita*, which displayed 53.33 percent repellency with class III at 40 nL/cm^2 concentration after 24 hours of exposure. Whereas, *M. arvensis* and *M. citrata* exhibited 66.66 and 53.33 percent repellency towards *S. oryzae* at 173 nL/cm^2 concentration after 24 hours of exposure, which comes under class IV and III categories, respectively. The Median Repellent concentration (RC_{50}) of the mint oils were 5.9 nL/cm^2 (*M. spicata*), 36.3 nL/cm^2 (*M. piperita*), 70.7 nL/cm^2 (*M. arvensis*) and 128.3 nL/cm^2 (*M. citrata*), and the time taken for 50 per cent repellency (RT_{50}) were 2.30 h, 3.00 h, 4.50 h and 5.30 h, respectively. Thus, it is concluded that though all the mint essential oils exhibited repellent action against rice weevil, *S. oryzae*, in stored rice, the spearmint oil, *M. spicata* exhibited the maximum repellency effect within a short period against rice weevil.

Keywords: Mint essential oils, *Mentha spicata*, *Mentha piperita*, *Mentha arvensis*, *Mentha citrata*, rice weevil, repellent toxicity, RC_{50}, RT_{50}

Introduction
The rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), is the largest and most popular storage pest of raw cereals (Champ & Dyte, 1976) [8]. This pest emerged in India, dispersed through trade, and presently has a worldwide distribution. In India, postharvest losses of food grain surpass 12 to 16 million metric tonnes annually (Singh 2010) [38]. *S. oryzae*, a rice weevil, is one of the most detrimental insect pests, causing 10 to 65 percent damage under moderate storage conditions and 80 percent damage under long storage conditions (Park *et al*., 2004) [29]. Adult weevils eat rice and deposit their eggs in rice kernels, where the larvae can grow into adults (Lee *et al*., 2001) [24].

Plant products have played an important role in traditional crop pest and disease vector control methods (Stoll, 1988) [41]. Plant oils have long been used to control the storage insect pests (Yun-tai & Burkholder, 1981) [46] and they are especially effective for small storage systems. Many spices and herbs as well as their extracts are known to have insecticidal properties, which are frequently found in essential oil fractions (Brattsten, 1983; Schmidt *et al*., 1991; Shaaya *et al*., 1991) [7, 33, 35]. Secondary metabolites obtained from plants are reported to provide resistance against predators and pathogens as well as intra and interspecific attractants and some secondary metabolites possess medicinal properties, antiviral, antihypertensive, bronchodilation and hepatoprotective properties (Seigler 1998, Moore 2014).

The mint plant belongs to the Lamiaceae (Syn. Labiatae) family (Harley *et al*., 2004) [14]. Secondary metabolites such as terpenes/essential oils and other components are found in the epidermal glands of leaves, stems, and reproductive structures in the majority of Lamiaceae plants. The most important mint species essential oils commercially used are spearmint, *Mentha spicata* L., peppermint, *Mentha piperita* L., corn mint, *Mentha arvensis* L. and bergamot mint, *Mentha citrate* L. Corn mint, *M. arvensis*, is the only one of these species that is cultivated for oil production in India (Oudhia, 2003) [28]. Peppermint oil is one of the essential oils and they have two main components menthol and menthone (Mimica-Dukic *et al*., 2003) [25]. On the other hand, spearmint is high in carvone and is widely used as spices and grown in many countries (Kokkini *et al*., 1995) [20].

Kumar *et al*., (2010) [21] reviewed the insecticidal properties of mentha oil and extract against storage insects. In this study, we investigate the repellent action of mint essential oils to manage rice weevil.

Materials and Methods

The research was conducted at the Insectary, Department of Agricultural Entomology, Agricultural College and Research Institute (9.925°N, 78.119°E), Madurai, Tamil Nadu from 2021 to 2022. The mint essential oils viz., spearmint oil, *M. spicata*, peppermint oil, *M. piperita*, corn mint oil, *M. arvensis* and bergamot mint oil, *M. citrate*, used in the laboratory experiments were obtained from the Spices Board, Uttar Pradesh, India.

Mass culturing of test insect

Rice weevil, *S. oryzae* was reared using rice grains, which were devoid of any insecticidal contamination. To sustain the continuous availability of insects for subsequent studies, 400 to 500 adults were introduced from the stock culture into a glass jar (500ml) containing 500 g of rice grains as culture media. The jars were covered with a muslin cloth to permit airflow in and secured with rubber bands. The culture was maintained at 28±2 ^{o}C temperature and 60±5% relative humidity (Ahmed, 1996) [4].

Repellency test

For the experiment, a nine cm diameter filter paper was cut into two halves. The repellency effect of essential oils was tested by uniformly applying four mint oil species. The concentrations of different mint essential oils were fixed based on the preliminary range finding studies. Various concentrations of essential oil diluted with hexane were applied on one half of the filter paper (200 µl/31.75 cm^2) and hexane alone on the other halves and used as an untreated control. The solvent was evaporated from both the treated and untreated half circles. The entire disc of treated and untreated half circles was remade and placed on the Petri dishes by attaching sticky tape from the lower side. Twenty newly emerged adult weevils were released between the two halves and covered with the lid. The inner side of the lid was coated with Vaseline to prevent the weevil from staying on the lid, and the treatment was replicated thrice. *S. oryzae* adults were counted on the treated and untreated halves at one-hour intervals from one to twenty-four hours. Talukder and Howse (1994) [42], Anandhabhairavi *et al*., (2021) [6]. The data was expressed as a percentage of repulsion (PR) using the formula (Valsala and Gokuldas, 2015) [43].

Repellency (%) = NC-NT/NC+NT x 100

Where,
NC = % of weevils observed in the control half.
NT = % of weevils observed in the treated half.

Concentrations were classified into different classes based on their percent repellency. The repellency class 0 included 0.01-0.1 percent repellency, 0.1-20 is classified as class I, 20.1-40 is classified as class II, 40.1-60 is classified as class III, 60.1-80 is classified as class IV and 80.1-100 is classified as class V.

Statistical analysis

The experiment was conducted at Completely Randomized Design (CRD). The percent repellency was estimated and subjected to arcsine transformation, later they were statistically analyzed using SPSS for Windows (Version 16) software to carry out an analysis of variance (ANOVA). Grouping of data was done by using Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) [12].

Result and Discussion

The results showed that all the botanicals were toxic to *S. oryzae*. Out of the four mint essential oils tested, spearmint, *M. spicata* had the highest repellent activity against rice weevil, followed by peppermint, *M. piperita*, corn mint, *M. arvensis* and bergamot mint oil, *M. citrata* exhibited the lowest repellent effect. Mint essential oil samples were found to have fumigation and repellent properties against a variety of storage pests *viz*., *Tribolium castaneum* Herbst., *S. oryzae*, *Acanthoscelides obtectus* Say., and others (Peeyush Kumar *et al*., 2010). Out of the 30 botanical families, the Lamiaceae family was the most commonly used, because essential oils are derived from natural resources, they are a sustainable alternative for controlling Coleopterans insects in stored grains. These oils may act as a contact, fumigant, repellent, antifeedant, oviposition inhibitor and other functions (Stefanazzi *et al*., 2006; Werdin-Gonzalez *et al*., 2008) [40, 44].
In this study, the repellency effect of spearmint oil *M. spicata* was measured at different hours and concentrations. *M. spicata* at 12 nL/cm^2 showed maximum repellency effect in different hours *viz.*, 1 h (33.33%), 2 h (43.33%), 3 h (46.66%), 4 h (46.66%), 5 h (52.60%), 6 h (60.66%) and 24 h (66.66%). It revealed that the repellency effect was gradually progressing with the time of exposure and reached a maximum of 66.66 percent and was classified under the Class III category. The mean per cent repellency of spearmint oil at different concentration *viz.*,3.0 nL/cm^2 (16.19%), 4.0 nL/cm^2 (22.81%), 6.0 nL/cm^2 (28.95%), 7.0 nL/cm^2 (35.21%), 9.0 nL/cm^2 (39.48%), 11.0 nL/cm^2 (45.21%) and 12.0 nL/cm^2 (49.10%). The median repellency concentration of *M. spicata* against rice weevil, *S. oryzae* was 5.90 nL/cm^2 (RC_{50}) at 24 hours of exposure with a median repellency time (RT_{50}) of 2.30 h at 12.0 nL/cm^2. Earlier studies were also in support of this finding and they are listed below. Anandhabhairavi *et al*., 2021 [6] observed that out of 11 botanical extracts used against rice weevil, *S. oryzae*, the hexane extracts of certain botanicals *viz*., *M. spicata* and *O. sanctum* at 5% possessed the highest mean repellency effect (76.11 percent). In addition, it was also found to possess a mosquito repellent effect (Elizabeth *et al*., 2017) [27]. Mint essential oil samples were found to have fumigation and repellent properties against a variety of storage pests *viz*., *T. castaneum*, *S. oryzae*, *A. obtectus* and others (Peeyush Kumar *et al*., 2010). L-carvone (0.1%) highest repellent (10-100%) action against rice weevil, *S. oryzae* (Malgorzata *et al*., 2020).
The results on the peppermint oil, *M. piperita* showed the highest repellency effect against *S. oryzae* at the concentration of 40 nL/cm^2 at different hours, including 1 h (33.33%), 2 h (36.66%), 3 h (40.0%), 4 h (43.33%), 5 h (46.66%), 6 h (50.00%) and 24 h (53.33%). The repellency rate increased steadily until it reached its maximum (53.33%), which falls under class III repellency. The mean repellency of peppermint oil was measured at various concentrations, including 3.0 nL/cm^2 (5.70%), 9.0 nL/cm^2 (19.03%), 15.0 nL/cm^2 (24.72%), 22.0 nL/cm^2 (29.97%), 28.0 nL/cm^2 (35.21%), 34.0 nL/cm^2 (39.01%) and 40.0 nL/cm^2 (43.31%). The median repellent effect of *M. piperita* against rice weevils was 36.30

nL/cm^2 after 24 hours of exposure and the median time to repel the 50% of insect was 3.00 h at 40 nL/cm^2 concentration. Ezhil Vendan *et al*., (2017) observed that at a 400 µl/L air concentration, peppermint oil outperformed the other essential oils in terms of killing *S. oryzae*, causing 83% mortalities in with-food circumstances, respectively, over a 72-hour exposure. After 24 hours of exposure, 1.0 percent pepper mint essential showed 73.3 percent repellency against rice weevil (Abdel-fattah *et al*., 2016). Shaaya *et al*., (1999) reported 85 and 7.5 µl/L air as the LC_{50} concentrations for peppermint oil treatments against *S. oryzae*. Peppermint oil is one of the most popular and widely used essential oils, mostly because of its main component's menthol and menthone (Gul, 1994) [13]. Samarasekera *et al*., (2008) [32] investigated the effect of essential oil of *M. piperita* against local mosquitoes and subsequently carried out its GC analysis obtaining menthol (41%) and menthone (24%) as principal constituents. The phytochemical present in *M. piperita* were menthol (46.98%), they should strong insecticidal and repellency activity against rice weevil (Shaaya, 1999; Aggarwal *et al*., 2001) [3].

Regarding the maximum repellency of corn mint oil, *M. arvensis*, it was calculated at a concentration of 173 nL/cm^2 during a period of 1 h (33.33%), 2 h (36.66%), 3 h (40.0%), 4 h (40.0%), 5 h (43.33%), 6 h (53.33%) and 24 h (66.66%). It was discovered that the repellency impact increased progressively throughout the exposure, peaked at 66.66%, and was as Class III. The mean repellency of corn mint oil was tested at various concentrations, including 7.0 nL/cm^2 (7.61%), 15.0 nL/cm^2 (18.55%), 31.0 nL/cm^2 (23.32%), 47.0 nL/cm^2 (28.52%), 78.0 nL/cm^2 (31.41%), 110.0 nL/cm^2 (36.62%), 141.0 nL/cm^2 (40.44%) and 173.0 nL/cm^2 (53.11%). The median time required for *M. arvensis* to repel 50% of *S. oryzae* insects was 4.50 h at the concentration of 173 nL/cm^2. The median repellent effect of *M. arvensis* against *S. oryzae* was 70.75 nL/cm^2 after 24 hours of exposure. Earlier studies reported that the *M. arvensis* was highly repellent to rice weevil, *S. oryzae* and red flour beetle, *T. castaneum* (Bhuwan Bhaskar Mishra *et al*., 2013). *M. arvensis* essential oils have insecticidal and oviposition inhibitory properties in maize weevils, as well as repellent activity against *S. zeamais* adults (Chaubey, 2018) [10]. According to some studies, *M. arvensis* is the richest source of natural menthol (Sharma and Tyagi, 1991; Shasany *et al*., 2000) [36, 37]. *M. arvensis* has been frequently used for various insecticidal assays (Kumar *et al*., 2009; Pavela, 2005) [23, 30]. Earlier Aggarwal *et al*., 2001 [3] reported the repellency effect of L-menthol against *S. oryzae* at 0.353 µg/cm² dose (82-100%).

In *M. citrata*, the repulsive activity was observed at various times and concentrations. The concentration of 173 nL/cm^2 at various times, including 1 h (26.6%), 2 h (30.0%), 3 h (36.6%), 4 h (40.0%), 5 h (43.33%), 6 h (50.0%) and 24 h (53.33%) showed repellency effect against *S. oryzae*. The highest repellent effect was (53.33%) and it comes under the class II category. The mean repellency of bergamot mint oil at various concentrations, including 7 nL/cm^2 (9.52%), 15 nL/cm^2 (13.79%), 31 nL/cm^2 (18.07%), 47 nL/cm^2 (23.31%), 78 nL/cm^2 (28.0%), 110 nL/cm^2 (32.41%), 141 nL/cm^2 (36.14%) and 173 nL/cm^2 (39.97%). The medial repellent effect of *M. citrata* oil was 128.3 nL/cm^2 after 24 hours of contact and the medial repellent time was 5.30 h at 173 nL/cm^2 concentration. After 24 hours of exposure, bergamot mint oil was found to have repellent activity against rice weevil (Cosimi *et al*., 2008). The phytochemical present in *M. citrata* was linalool (51%) and carvone (23.42%) (Sartoratto and Augusto 2003). Kłyś *et al*., 2020 [19], reported the highest repellent and toxic effect of 0.1% L-carvone on *S. oryzae*. Kabugi *et al*., 2013 reported the repellency effect of linalool against all instar nymphs and females of clothing wax cicada, *Lycorma delicatula* White. and *S. oryzae*, respectively.

It is concluded that all the tested mint essential oils possess a repellency effect, with maximum efficiency in the *M. spicata* at 12 nL/cm^2 after 24 hours of contact against *S. oryzae* in rice. Hence, the spearmint essential oil, *M. spicata* can be used to protect the rice grains from the *S. oryzae* infestation.

Table 1: Repellent toxicity of spearmint essential oil, *Mentha spicata* against rice weevil, *Sitophilus oryzae*

Treatments	Repellency (%)#							Mean repellency (%)	Class mean repellency
	1 h	2 h	3 h	4 h	5 h	6 h	24 h		
T_1: *M. spicata* 3.0 nL/cm^2	0.00±0.00 (4.05)^c	13.33±0.24 (19.30)^d	20.00±0.33 (24.25)^e	20.0±0.59 (26.92)^c	20.00±0.11 (26.92)^d	20.0±1.23 (26.92)^c	20.00±1.99 (26.92)^c	16.19 (22.17)^d	I
T_2: *M. spicata* 4.03 nL/cm^2	13.33±0.00 (19.29)^c	23.33±0.98 (29.12)^{cd}	23.33±0.57 (29.12)^{de}	23.33±1.22 (29.12)^{bc}	23.3±1.25 (29.12)^{cd}	26.6±0.41 (31.32)^c	26.66±0.55 (31.32)^{bc}	22.81 (27.88)^{cd}	II
T_3: *M. spicata* 6.0 nL/cm^2	23.33±0.12 (29.12)^{bc}	26.66±1.28 (31.32)^{bcd}	26.66±1.23 (31.32)^{cd}	26.66±1.54 (31.32)^{bc}	30.0±0.22 (33.52)^{bcd}	33.33±1.27 (35.52)^{bc}	36.66±1.23 (37.52)^{abc}	28.95 (32.78)^{bc}	II
T_4: *M. spicata* 7.0 nL/cm^2	26.66±1.29 (31.32)^{abc}	33.33±1.43 (35.52)^{bc}	33.33±1.58 (35.52)^{bc}	33.33±1.66 (35.52)^{ab}	33.33±1.22 (35.52)^{abcd}	36.6±1.35 (37.52)^{ab}	50.0±1.58 (45.29)^{ab}	35.21 (36.60)^{abc}	II
T_5: *M. spicata* 9.0 nL/cm^2	30.00±0.58 (33.52)^{ab}	36.66±0.89 (37.52)^{ab}	36.6±0.94 (37.52)^{bc}	36.66±0.61 (37.52)^{bc}	40.0±1.54 (39.52)^{abc}	43.33±0.77 (41.44)^{ab}	53.33±0.63 (47.21)^a	39.48 (42.22)^{ab}	II
T_6: *M. spicata* 11.0 nL/cm^2	33.33±1.83 (35.52)^a	40.00±1.12 (39.52)^{ab}	40.0±1.66 (39.44)^{ab}	43.33±0.25 (41.44)^{ab}	46.66±1.91 (43.36)^{ab}	53.33±0.87 (47.21)^a	60.0±0.38 (51.06)^a	45.21 (42.50)^a	III
T_7: *M. spicata* 12.0 nL/cm^2	33.33±0.88 (35.52)^a	43.33±1.33 (41.44)^a	46.66±0.81 (43.37)^a	48.66±0.35 (43.36)^a	52.60±0.23 (43.36)^a	60.66±0.87 (51.15)^a	66.66±0.47 (55.08)^a	49.10 (44.75)^a	III
SED	0.18	0.18	0.15	0.30	0.24	0.20	0.23		
P-value	<0.0001**	<0.0001**	<0.0001**	<0.0001**	<0.0001**	<0.0001**	<0.0001**		

#Mean values of three replications are represented as mean ± standard deviation.
Figures in the parentheses are arcsine transformed values (x+0.5).
Mean followed by the same letter are not significantly different from each other, Tukey's test ($p \leq 0.05$).
SED: Standard Error of the Difference; h: hours **Highly Significant.

Table 2: Repellent toxicity of peppermint mint essential oil, *Mentha piperita* against rice weevil, *Sitophilus oryzae*

Treatments	Repellency (%)#							Mean repellency (%)	Class mean repellency
	1 h	2 h	3 h	4 h	5 h	6 h	24 h		
T1: *M. piperita* 3.0 nL/cm^2	0.00±0.00 (4.05)^{b}	0.00±0.00 (4.05)^{c}	0.00±0.23 (4.05)^{b}	0.00±0.11 (4.05)^{e}	6.66±0.23 (11.67)^{e}	13.3±0.38 (21.14)^{d}	20.00±0.77 (26.56)^{e}	5.70 (10.79)^{d}	I
T2: *M. piperita* 9.0 nL/cm^2	6.66±0.00 (11.67)^{b}	13.33±0.51 (19.29)^{bc}	20.0±0.47 (26.92)^{ab}	20.00±11.54 (26.92)^{de}	20.00±1.58 (29.12)^{de}	23.33±1.95 (26.07)^{cd}	30.00±1.25 (33.21)^{de}	19.03 (24.74)^{cd}	I
T3: *M. piperita* 15.0 nL/cm^2	13.33±0.23 (19.29)^{ab}	20.0±1.65 (26.92)^{bc}	23.33±1.23 (29.12)^{ab}	23.33±5.77 (29.12)^{cd}	26.66±1.68 (31.32)^{cd}	33.33±0.87 (35.21)^{bc}	33.33±0.77 (35.21)^{cd}	24.72 (26.22)^{bc}	II
T4: *M. piperita* 22.0 nL/cm^2	20.00±0.44 (26.92)^{ab}	23.33±1.22 (29.12)^{ab}	26.66±0.88 (31.32)^{ab}	30.00±11.54 (33.32)^{bcd}	33.33±1.37 (35.32)^{bcd}	36.66±1.97 (37.22)^{bc}	40.00±0.87 (39.14)^{bcd}	29.97 (27.60)^{ab}	II
T5: *M. piperita* 28.0 nL/cm^2	26.66±1.23 (31.32)^{ab}	26.66±0.23 (31.32)^{a}	30.0±0.34 (33.32)^{a}	33.33±10.0 (35.52)^{abc}	43.33±0.32 (41.44)^{abc}	43.33±0.35 (41.15)^{abc}	43.33±1.39 (41.15)^{abc}	35.21 (30.58)^{ab}	II
T6: *M. piperita* 34.0 nL/cm^2	30.0±1.45 (33.52)^{ab}	33.33±0.57 (35.52)^{a}	33.33±1.47 (35.32)^{a}	40.00±10.0 (39.52)^{ab}	43.33±1.97 (41.44)^{ab}	46.66±1.82 (43.07)^{ab}	46.66±0.98 (43.07)^{ab}	39.01 (38.78)^{a}	II
T7: *M. piperita* 40.0 nL/cm^2	33.33±0.68 (35.52)^{a}	36.66±1.35 (37.52)^{a}	40.0±0.36 (39.44)^{a}	43.33±5.77 (41.44)^{a}	46.66±0.38 (43.36)^{a}	50.00±0.99 (45.0)^{a}	53.33±1.33 (46.92)^{a}	43.31 (41.31)^{a}	III
SED	0.19	0.17	0.25	0.15	0.17	0.30	0.29		
P-value	0.01**	<0.0001**	0.04**	<0.0001**	<0.0001**	<0.0001**	<0.0001**		

#Mean values of three replications are represented as mean ± standard deviation.
Figures in the parentheses are arcsine transformed values (x+0.5).
Mean followed by the same letter are not significantly different from each other, Tukey's test ($p \leq 0.05$).
SED: Standard Error of the Difference; h: hours **Highly Significant.

Table 3: Repellent toxicity of corn mint essential oil, *Mentha arvensis* against rice weevil *Sitophilus oryzae*

Treatments	Repellency (%)#							Mean repellency (%)	Class mean repellency
	1 h	2 h	3 h	4 h	5 h	6 h	24 h		
T1: *M. arvensis* 7.0 nL/cm^2	0.00±0.00 (4.05)^{b}	0.00±0.00 (4.05)^{b}	6.66±0.51 (11.67)^{d}	6.66±0.22 (11.67)^{d}	6.66±0.55 (11.67)^{d}	13.33±0.36 (29.12)^{e}	20.0±1.00 (26.92)^{f}	7.61 (14.16)^{e}	I
T2: *M. arvensis* 15.0 nL/cm^2	6.66±0.00 (11.67)^{b}	13.3±0.00 (19.29)^{b}	20.0±0.22 (26.92)^{d}	20.00±0.36 (26.66)^{d}	23.33±0.12 (29.12)^{cd}	23.33±0.96 (35.52)^{de}	23.33±0.35 (29.12)^{ef}	18.55 (25.46)^{de}	I
T3: *M. arvensis* 31.0 nL/cm^2	13.33±0.55 (19.29)^{ab}	20.0±1.32 (26.92)^{ab}	23.3±0.24 (29.12)^{cd}	20.0±0.65 (30.92)^{cd}	26.66±1.23 (31.32)^{cd}	33.33±0.85 (37.52)^{de}	26.66±0.36 (31.32)^{de}	23.32 (28.91)^{de}	II
T4: *M. arvensis* 47.0nL/cm^2	20.0±1.25 (26.62)^{ab}	23.33±0.55 (29.12)^{ab}	26.6±1.32 (31.32)^{bc}	26.66±1.00 (31.32)^{cd}	30.0±0.32 (33.52)^{bc}	36.66±0.14 (39.52)^{cd}	36.66±0.98 (37.52)^{cde}	28.52 (38.58)^{cd}	II
T5: *M. arvensis* 78.0 nL/cm^2	23.3±0.22 (29.12)^{ab}	26.66±0.57 (31.32)^{ab}	30.0±0.33 (33.52)^{bc}	30.0±0.25 (33.52)^{bc}	30.0±0.32 (33.52)^{ab}	40.0±0.69 (45.26)^{cd}	40.0±0.15 (39.44)^{bcd}	31.41 (35.10)^{bc}	II
T6: *M. arvensis* 110.0 nL/cm^2	26.66±1.36 (31.32)^{ab}	30.0±0.77 (33.52)^{ab}	33.33±0.41 (35.52)^{abc}	33.33±0.57 (35.52)^{bc}	36.66±0.65 (37.52)^{ab}	46.66±1.22 (45.28)^{abc}	50.00±0.36 (43.36)^{abc}	36.62 (37.42)^{bc}	II
T7: *M. arvensis* 141.0 nL/cm^2	30.0±1.81 (33.52)^{ab}	33.3±0.58 (35.52)^{ab}	36.66±1.25 (37.52)^{ab}	36.6±0.32 (37.52)^{ab}	40.0±0.17 (39.52)^{a}	50.0±1.36 (47.21)^{ab}	56.66±0.25 (49.13)^{ab}	40.44 (39.99)^{ab}	II
T8: *M. arvensis* 173.0 nL/cm^2	33.33±0.22 (35.52)^{a}	36.66±0.14 (37.52)^{a}	40.0±0.36 (39.52)^{a}	40.0±0.35 (39.52)^{a}	43.33±0.69 (41.44)^{a}	53.33±0.87 (47.21)^{a}	66.66±0.74 (55.08)^{a}	53.11 (42.25)^{a}	III
SED	0.17	0.21	0.16	0.16	0.24	0.26	0.26		
P-value	0.02**	<0.0001**	<0.0001**	<0.0001**	<0.0001**	<0.0001**	<0.0001**		

#Mean values of three replications are represented as mean ± standard deviation.
Figures in the parentheses are arcsine transformed values (x+0.5).
Mean followed by the same letter are not significantly different from each other, Tukey's test ($p \leq 0.05$).
SED: Standard Error of the Difference; h: hours **Highly Significant.

Table 4: Repellent toxicity of bergamot mint essential oil, *Mentha citrata is* against rice weevil, *Sitophilus oryzae*

Treatments	Repellency (%)#							Mean repellency (%)	Class mean repellency
	1 h	2 h	3 h	4 h	5 h	6 h	24 h		
T1: *M. citrata* 7.0 nL/cm^2	0.00±0.00 (4.05)^{b}	0.00±0.00 (4.05)^{c}	6.66±0.00 (11.67)^{d}	6.66±0.00 (11.67)^{e}	13.33±0.52 (19.29)^{f}	20.0±0.56 (26.92)^{d}	20.0±0.87 (26.92)^{d}	9.52 (14.93)^{e}	I
T2: *M. citrata* 15.0 nL/cm^2	0.00±0.00 (4.05)^{b}	6.66±0.69 (11.67)^{bc}	6.66±0.57 (11.67)^{cd}	13.33±0.25 (19.29)^{de}	20.0±0.54 (26.12)^{ef}	23.33±1.23 (29.12)^{d}	26.66±0.25 (31.32)^{cd}	13.79 (19.03)^{de}	I
T3: *M. citrata* 31.0 nL/cm^2	6.66±0.00 (11.67)^{b}	6.66±0.25 (11.67)^{abc}	13.33±0.12 (19.29)^{bcd}	20.0±0.84 (26.92)^{cde}	23.33±0.36 (29.12)^{ef}	26.66±0.98 (31.32)^{cd}	30.0±0.47 (33.52)^{bcd}	18.07 (24.50)^{cde}	I
T4: *M. citrata* 47.0 nL/cm^2	6.66±0.25 (11.67)^{ab}	13.33±0.15 (19.29)^{abc}	23.33±0.87 (29.12)^{bcd}	23.33±1.25 (29.12)^{cd}	26.66±0.98 (31.32)^{def}	33.33±0.77 (35.52)^{bcd}	36.66±0.14 (37.52)^{bc}	23.31 (27.65)^{cd}	II
T5: *M. citrata* 78.0 nL/cm^2	13.33±0.33 (19.29)^{ab}	20.0±1.32 (26.45)^{ab}	26.66±0.45 (31.32)^{bc}	26.66±0.54 (31.32)^{bc}	26.66±0.74 (31.32)^{cde}	36.66±0.56 (37.52)^{abc}	43.33±0.87 (41.44)^{ab}	28.00 (31.22)^{bc}	II
T6: *M. citrata* 110.0 nL/cm^2	20.00±1.23 (26.92)^{ab}	23.3±0.12 (29.12)^{ab}	30.33±0.69 (33.52)^{ab}	30.0±0.69 (33.32)^{abc}	33.33±0.65 (35.52)^{abc}	43.33±0.58 (41.44)^{ab}	46.66±0.12 (43.36)^{ab}	32.41 (34.73)^{abc}	II
T7: *M. citrata* 141.0 nL/cm^2	23.33±0.54 (29.12)^{ab}	26.6±0.33 (31.32)^{ab}	33.33±0.87 (35.52)^{ab}	33.33±0.38 (35.32)^{ab}	36.66±0.87 (37.52)^{ab}	46.66±0.54 (43.36)^{a}	53.33±0.21 (47.21)^{a}	36.14 (37.06)^{ab}	II
T8: *M. citrata* 173.0	26.66±0.46	30.0±0.23	36.66±0.15	40.0±0.87	43.33±1.23	50.0±1.84	53.33±0.32	39.97	II

nL/cm²	(31.32)[a]	(33.32)[a]	(37.52)[a]	(39.52)[a]	(41.44)[a]	(45.28)[a]	(47.21)[a]	(39.36)[a]	
SED	0.18	0.20	0.20	0.19	0.20	0.19	0.18		
P-value	0.03**	0.01**	<0.0001**	<0.0001**	<0.0001**	<0.0001**	<0.0001**		

#Mean values of three replications are represented as mean ± standard deviation.
Figures in the parentheses are arcsine transformed values (x+0.5).
Mean followed by the same letter are not significantly different from each other, Tukey's test ($p \leq 0.05$).
SED: Standard Error of the Difference; h: hours **Highly Significant.

Table 5: Median Repellency concentration of mint essential oils against rice weevil, *Sitophilus oryzae*

Mint essential oils	χ2	*Df* (n-2)	RC_{50} (nL/cm²)	Fiducial Limits (50%)		RC_{95} (nL/cm²)	Fiducial Limits (95%)		Slope
				Lower	Upper		Lower	Upper	
M. spicata at 24 h	11.02 n.s	5	5.90	5.31	6.55	21.27	16.11	28.09	3.17
M. piperita at 24 h	10.63 n.s	5	36.30	20.91	61.92	22312.6	304.94	163262.6	0.58
M. arvensis at 24 h	12.30 n.s	6	70.75	54.52	91.82	2474.64	918.21	6669.2	0.83
M. citrata at 24 h	12.33 n.s	6	128.3	88.80	162.03	12119.1	1867.0	78668.6	0.59

Control-Nil mortality.
n.s = Not Significant at $p<0.05$ level.
RC_{50} = Repellency Concentration that Repels 50 per cent of the exposed larvae.
RC_{95} = Repellency Concentration that Repels 95 per cent of the exposed larvae.
χ^2 = Chi Square; *df* = Degrees of freedom; UL = Upper Limit; LL = Lower Limits; h-hours.
nL = Nano litre; cm² = Square centimeter.

Table 6: Median Repellency Time of mint essential oils against rice weevil, *Sitophilus oryzae*

Mint essential oils	χ2	*df* (n-2)	RT_{50} (h)	Fiducial Limits (50%)		RT_{95} (h)	Fiducial Limits (95%)		Slope
				LL	UL		LL	UL	
M. spicata 12nL/cm²	11.05 n.s	5	5.30	3.50	7.90	26.50	16.00	45.30	1.45
M. piperita 40 nL/cm²	11.03 n.s	5	6.00	4.00	9.80	30.00	18.00	51.30	2.63
M. arvensis 173 nL/cm²	10.80 n.s	5	6.30	4.30	10.30	38.00	21.50	69.50	2.55
*M. citrata*173 nL/cm²	11.01 n.s	5	6.45	4.50	12.50	68.50	31.00	150.0	1.33

Control - Nil mortality.
n.s = Not Significant at $p<0.05$ level.
RC_{50} = Repellency Time that Repels 50 per cent of the exposed larvae.
RC_{95} = Repellency Time that Repels 95 per cent of the exposed larvae.
χ^2 = Chi Square; *df* = Degrees of freedom; UL = Upper Limit; LL = Lower Limits; h-hours.
nL = Nano litre; cm² = Square centimeter.

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